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Environmental Stressors Affecting Human Physiology and Performance in Northern Australia

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DEPARTMENT OF DEFENCE
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ABSTRACT

Deployment of military staff to the north exposes them to the debilitating effects of high heat and humidity. This paper summarises the findings of a series of visit to several military establishments in northern Australia and a training battalion in NSW. Areas of research priority were identified and recommendations were given to address ADF's requirements in human physiological performance and survavibility in adverse environments.

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Executive Summary

Past experience from major military exercises in Australia such as Kangaroo-92 revealed that poorly acclimatized troops suffered numerous heat casualties. The problem is compounded by the requirements to operate in rugged terrains and uncomfortable environments, and, to perform physical demanding duties despite the lack of ergonomic considerations in some older military vehicles, helicopters and equipment. Thus, the ability of ADF to operate in this part of Australia may be compromised.

Due to these concerns, an ADL task on the 'Physiological Limits Upon Performance' was set up to review the critical issues hampering the physiological capabilities of soldiers deployed to the North. This report summarises the discussions and findings of the visits to military units in the north and in NSW. A brief account of the areas of operation, including the geographical features, climatic conditions, and environmental stressors is given. The likely physiological strains and performance deterioration experienced by soldiers in relation to these stressors is discussed. Finally, a list of research areas, with prioritization of those that may have direct impacts on operational effectiveness was recommended. A longer term R&D program based on these recommendations will fulfil the ADF's requirements to enhance the physiological capability of its personnel.

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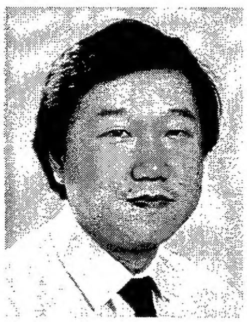

Tony Wai-Man Lau graduated in Hong Kong in 1979 majoring in Biology and Biochemistry. He then furthered his studies and obtained a M.Phil. degree in Environmental Biology in 1981. With the support of a Coucher Foundation Scholarship, he commenced a doctorate study in the University of Melbourne and was awarded a Ph.D. degree in Environmental Toxicology. After a short spell of employment with the Unipath Pathology Laboratory, he joined MRL as an Experimental Officer. His inital work involved studying the pharmacology of nerve agents leading to improved methods of prophylaxis and therapy. He was promoted to a Research Scientist in 1987 and subsequently to a Senior Research Scientist in 1993. He then moved into a new area of thermal physiology and was involved in the Human Sciences Review for DSTO. He is currently the Alternate Task Manager of the Personnel Protection and Performance Task.

Contents

1. Introduction

The security of Australia relies on the presence of a strong national defence force and a viable industrial base to support sustained operations in times of military confrontation. To successfully defend Australia, our defence forces must be highly motivated, independent, well organised and possess the knowledge and skill to utilize advanced technology and weapons to deter and repel aggressors.

In the past, Australia had been able to maintain a technological edge over the neighbouring countries in our region. However, recent economic booms in the Asia-Pacific rim have given some of these nations the economic power to acquire the most advanced military hardware available. Thus, our technological advantages in weapon systems are being greatly eroded. One way to address this inbalance is to identify means to improve the ADF's operational efficiency. These include the intelligent use of resources and weapons and the ability to outperform our adversaries physically and mentally. To fulfil these requirements, a comprehensive review of Human Factors(HF) capability within the defence community is required. Appropriate priorities and guidelines for research directives must be set to meet the requirements of ADF in this area.

Strategic guidance for Australia states that 'self reliance' and 'defence in depth' are the two fundamental strategies critical to our national security (1). This requires the ADF to be capable of executing all tasks in all environments; although co-operation and support from our allies may be subsequently sought. Our defence forces must be alert and ready for deployment at short notice. They must understand their capabilities and vulnerabilities and must be capable of exploiting our geography for military advantages.

Australia is a big continent with enormous natural resources. There is no other country adjoining its land border. This vast sea-air gap provides a significant barrier to hostile forces attempting to invade. The long coastline and sparse population in the Northern region, however, has made Australia vulnerable to incursion by limited military expeditions. These forces may occupy population centres for a short period or attack military installations and assets of national importance, thus allowing opportunists the benefit of short-term political publicity. While it is not possible to predict the outcome of a military conflict, the unforgiving climatic conditions and the extensive and difficult terrains of northern Australia have made long-term territorial gain by our enemy highly unlikely. Yet complacency is inadvisable. In defence planning, priority must be given to develop capabilities to handle threats to the north with little warning time. Proper preparation of troops, including an understanding of the requirements to operate in the hot/dry and hot/wet environments, are critical for successful military manoeuvres in this part of our country. The ability to defend the north will depend on the co-ordinated applications of the full range of defence capabilities and the exploitation of local environments for the advantage of the Defence forces. This follows the guidance of 'defence in depth' as stated in the Defence White Paper 94 (2)

and will greatly minimize the risk of escalating the conflict to the eastern and western seaboards.

This report examines the physiological stresses imposed by the environment on the personnel of the ADF defending the north. Human physiology may be defined as the normal functions and activities of human body. In this context, they are those functions which are clearly not psychological. They are mainly the functions of the body as a machine. In certain areas, there are links between the physiological and psychological aspects of the body, eg sleep deprivation. They will be included in the consideration of their effects on ADF's operational capability in the north. Recommendations for future research work in Human Sciences to increase the capability of the ADF to operate despite these physiological stressors are also included.

2. Scope of Study

This study was an information collection and analysis exercise. It embraced regular discussions with key staff in Defence department organizations that have primary responsibility for the health of service personnel, the development of operational capabilities, the planning of operations, and scientific support to the Land Forces. These include the SGADF, DGFD(L), LHQ and SA-A. The study has the following objectives:

- Review the physiological limits and requirements for soldiers deployed to the north.
- Review environmental stressors in northern environments that impose physiological stress onto the soldiers.
- Explore options to minimize injuries due to these environmental stressors.
- Establish a framework and recommend priority for longer term research and development in the physiological area of Human Sciences.

As a first step to achieve these objectives, visits to a number of military units deployed to strategic locations in the north were arranged. Briefings with staff, and exposure to the work conditions and environments under which soldiers were required to carry out their duties assisted the investigator in focusing on the practical of physiological stress issues that soldiers may experience. The following military units were visited.

- The Pilbara Regiment, Karratha, WA - 16 to 17 Feb. 1995
- The Army Air Corp., Oakey, Qld - 1 to 2 March 1995
- The Army Training Battalion, Kapooka, NSW - 5 April 1995
- The 2 Cavalry Regiment, Palmerston, NT - 19 to 20 April 1995

In addition, the Defence Food Science Center (DFSC) in Scottsdale, Tas. was visited on 21 Feb. to discuss possibility in research collaboration in Human Sciences.

The choice of these military units for the visits was based on the following considerations.

- Troops (both mounted and dismounted) conducting surveillance and reconnaissance are probably working under extremely stressful conditions.
- The Pilbara and surrounding areas of Darwin have the two most dominating climatic patterns in Northern Australia ie. hot/dry and hot/wet pattern.
- These regions are also identified as the areas that incursions by enemy are most likely to occur.
- The need to understand and improve basic training for new recruits.
- The special work environment for Army air operations.

3. Findings of the Visits

A number of issues in HF relevant to operation of these military units were raised during the visits. They had already been reported elsewhere. Some of the issues are well known hazards and others may be mission specific. They are summarised below for further consideration.

- Heat stress and related injuries occur when soldiers perform physically demanding work in hot and humid environments. These include mounted soldiers in RSFU, LAV and tank; foot soldiers on patrol and in combat; pilots, refuellers and ground staff operating at an airfield.
- Soldiers suffer dehydration because of forgetfulness in replenishing their fluid loss or the water simply becomes too hot to consume.
- Rapid deterioration in performance, both physical and mental, occurs when working in hot environment. Soldiers become irritable and personal hygiene can be a problem when troops conduct continuous surveillance for several days.
- Options for heat acclimation need to be exploited.
- Dust storms and strong wind in open areas can cause eye injuries and reduction in ability to detect presence of enemy.
- Stress to eye muscles may occur from soldiers conducting observation duty.
- Excessive noise and vibrations in some aircraft and armoured vehicles particularly those models and types that have been in service for a long period of time.
- Better Army uniform that aids evaporative cooling.
- Sleep deprivation - troops on night mission cannot recover by sleeping during the day.
- Poor ergonomic design for some aircraft and armoured vehicles - potential for physical injury.
- High incidence of stress fracture of ankle in new recruits undergoing training.
- Sunburn in aviators.
- Requirement for a portable and user friendly device for heat stress monitoring and warning.

An examining of these issues indicates that they can be broadly categorized into heat stress management, performance deterioration, ergonomic and training. An understanding of the problems and requirements for military operation in the north will assist DSTO in providing a strong scientific support to ADF in the improved management of risk arising from these environmental stressors.

4. Areas of Operation

The entire area of operation of Northern Australia covers almost 3 million sq. km. The common consensus, however is that military conflict will probably occur with very short warning time and be of relatively small scale. It is logical to focus on the coastal regions as the area that incursions by enemy forces are likely to occur. Nevertheless, it is essential to have a good understanding of the geographical features and climatic conditions of the entire Northern Australia so that full advantage can be taken by our Defence forces of the geography of the territory.

Northern Australia is a generic term and generally refers to the part of Australia north to the tropic of Capricorn (23°30'S). Fig 1 shows the regional demarcation of Northern Australia. Facing the Indian Ocean is the Pilbara and Kimberley. To the north-east of Kimberley is Arnhem Land which faces the Timor and Arafura Seas. East of Arnhem Land and separated by the Gulf of Carpentaria is the Cape York Peninsula. The tip of the peninsula guards the Torres Strait and its eastern coast overlooks the Coral Sea. Inland and adjoining the Pilbara and Kimberley are several desert plains. These are the Great Sandy and Gibson Deserts. There are also other large desert plains flanking the borders of South Australia, Northern Territory and Queensland. These plains constitute the Simpson Desert which is separated from the Gibson Desert by the McDonald Ranges. The Great Dividing Range originates from the base of the Cape York Peninsular and extends southward towards the Tropic of Capricorn. The Range is made up of a belt of hills and rainforests separating the east coast and the inland areas. Moving further inland from the Great Dividing Ranges is the Channel Country which joins the Simpson Desert on the west.

The terrains in Northern Australia are extremely diverse and rugged. A large part is inaccessible to traffic, particularly in the wet season. This will certainly have influence on Defence operations and planning. A brief account of the geographical features of the major regions is given below to illustrate the variety of terrains which will impose a human factors cost on personnel operating across them (4 to 12).

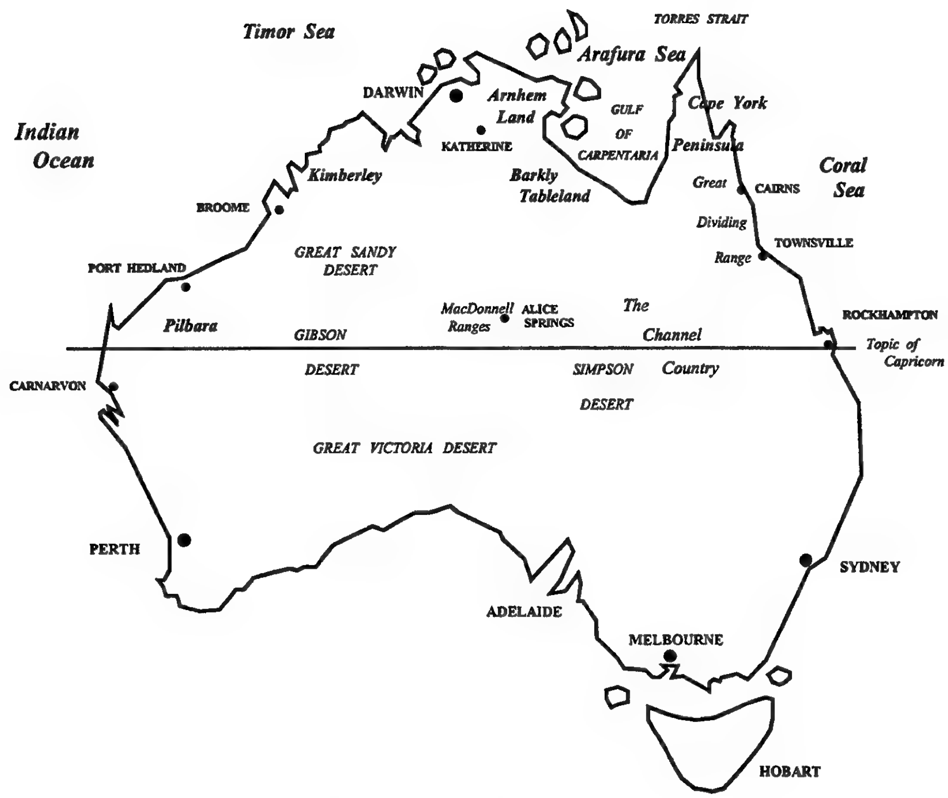

Fig 1. Regional Demarcation of Northern Australia

Kimberley

Occupying the northwest corner of Northern Australia is the Kimberley. It is bounded by Broom on the west, Fitzroy Crossing on the south, Kununurra to the east and the coastline facing Timor Sea to the north. The Kimberley is dominated by the Kimberley Plateau which is the northern extension of the Great Plateau of Western Australia. Its elevation is between 460 to 800m and consists of rugged mountains and elevated platform of sandstone and basalt deeply bisected by large rivers into gorges. The western half of the plateau is seriously eroded whereas the eastern portion is slightly less rugged and more consistent in feature. There are many small rivers forming deep narrow gorges along the northern and western coastline. The coastal landscape is generally undulating, cut by canyons and has steep slopes extending all the way to the irregular coastline.

Pilbara

Pilbara sits south of Kimberley and is flanked by $20^{\circ}S$ in the north, Tropic of Capricorn in the south, the borders of NT and WA in the east and Indian Ocean coastline in the west. Contained within the Pilbara is WA's highest and most rugged terrain. The coastline of the region is made up of mainly coastal dunes, salt flats and tidal swamps. Behind the coast towards east is a flat terrain covered with sand and gravel. In areas where occasional heavy rain occurs, gravel and clay surfaces are very common. Moving inland from the low lying parts of the northern coast of Pilbara is a granite plain. It rises gently further inland with little relief except granite tors or dykes of basic rocks. The whole plain is crossed by numerous flood channels where the regional river systems, which are dry most of the year, originate. The inner Pilbara is made up of granite and alluvial plains of various elevations, valleys, steep ranges and gorges of various depth. Some mountain elevations reach 1200m or more and most escarpments are abrupt and precipitous. The terrain is open with undulating plains covered by rocky and sandy earth. Except for isolated pools, most of the rivers in the region are dry except when inundated with short periods of heavy rain. They may rise to flood levels causing disruption to road transport.

To the east is the Great Sandy Desert. It is a great sandy plain with isolated low domed hills. Linear sand dunes have formed creating an inaccessible sandhill region. Closer to the coast the surface is still very sandy. There are no permanent watercourses in the area.

Arnhem Land

The land area lies within the torrid zone north of the Tropic of Capricorn. This region is relatively flat with elevations usually below 450m and forms part of the Australia's central lowlands. The low flat coastline, consisting mainly of sandy beaches and mud flats, can be flooded by tidal waves. The coast is dominated by mangroves. These, together with the adjoining sand ridges restrict movement into the inland areas. Coastal flood plains are significant feature of all major river systems. They are inundated by fresh water in wet season and form swamps, billabongs and are inaccessible. In dry months, they may be accessible.

Extending from the low plains from the coast is a range of table top plateaus with heights of 150 to 250m. Steep slopes of loose gravel leading to vertical rock escarpment of 50m or more are very common. The headwaters of many drainage systems originate in these escarpments forming wild and inaccessible gorges. Access to the high lands for tracked or wheeled vehicles is restricted and movement through the gorges and loose slopes is slow and difficult.

The Arnhem Land contains the largest river systems in the Northern Territories. Most rivers in the east coast are interlaced with non-perennial watercourses. They are usually dry in winter but flow in wet season. The larger rivers such as Roper, the South

Alligator, East Alligator, Daly and Victoria are all navigable for significant distances upstream from their outflow to the sea. In wet months, medium draft vessels can operate up to 150km upstream but river flows can change dramatically due to tidal changes. The river banks are usually steep and soft mud is exposed at low tide.

Cape York Peninsula and The Great Dividing Range

The terrain in this region varies from mud plain to dense tropical rainforest with the predominant Great Dividing Range extending towards the east coast. The coastline is largely irregular but becomes more uniform towards the south. Between the coastline and the eastern highland is the coastal plain. It is made up of sand-drift superimposed on soft Mesozoic sediments and layers of marine and alluvial deposits. The width of the plain can vary from a few hundred meters near Cardwell to tens of km at the south of the Gulf of Carpentaria. The great Dividing Range forms a series of high plateaus which divide the east- and west-flowing drainages. The highest summits (over 2200m) are mainly situated in the southeast. The elevation gradually decreases towards the north but is still relatively high in the Cape York Peninsula (between 600 to 1500m). Moving inland from the Range are highlands gradually merging into plains of lowland zone. Rainfall run-off flows eastward through the smooth open valleys, then through narrow rocky clefts to burst over the plateau edges in water falls before meandering across the alluvial plains of narrow coastal valleys. In the west, the waters flow first through open valleys; then gradually out onto the plains where the meandering waters slacken and eventually evaporate into the air.

By comparison, the Cape York Peninsula is relatively undisturbed. There are only rudimentary roads , tracks and airfields. Numerous streams from eastern and western watersheds create significant barriers to vehicle movements. Road access to a large part of the region is seasonally affected and off road travel in many areas is extremely difficult even during the dry. They usually become impossible to traverse in wet seasons.

The Deserts

The central region of Northern Australia is dominated by desert plains. This includes the Great Sandy Desert on the west, the Simpson Desert on the east and the central Gibson Desert. In general, these deserts are made up of sandy plains with isolated low hills. Linear seif dunes are common on the plain creating inaccessible sandhill regions. There are no permanent watercourses nor seasonal ones except briefly at the foot of some larger mesas.

5. Climatic Conditions

The climate of Northern Australia is characterised by high temperature, clear skies and rainfall which while generally low, may be very heavy for short periods and in tropical cyclones. The most distinctive seasonal change, particularly in these areas along the coastline, is the occurrence of a wet season in summer and a dry season in winter. The formation of the rainy season in this part of Australia is under the influence of hot and moist north-westerly flows of monsoonal air moving towards the central intertropical zone. During winter, the high pressure belt moves northward and Northern Australia is influenced mainly by mild, dry south-easterlies.

Tropical cyclones are associated with the intrusions of hot and moist tropical air. They usually bring in very heavy rain in coastal areas even after they move inland and lose intensity. Individual cyclones may control weather over northern Australia for periods up to three weeks. Their frequency of occurrence and tracks vary greatly from year to year. The average is about two per season over the north-west coast, one to two over the north-east coast and one in the Gulf of Carpentaria.

The climatic conditions of Northern Australia have the potential to generate serious challenges to military activities and planning. The heat and humidity can impose extreme physiological stresses on individuals who have to perform high levels of physical exertion out in the open. In terms of impact, floods, destructive wind, bushfires and repressive heat are the most serious hazards. Accurate weather forecasts and adequate preparation of troops operating in these climatic conditions are critical in enabling them to accomplish their missions. There are regional climatic differences within Northern Australia. An outline of the different characteristics of the individual weather patterns highlights the different requirements for troops deployed to these regions of Northern Australia (3 to 15).

Pilbara

The Pilbara is a semi-arid region characterised by high temperatures, low and variable rainfall and high evaporation. The temperature can reach over 40°C during summer months and may fall to 11°C in the coldest months. The effect of onshore winds will minimize temperature fluctuations at the coastal districts but fluctuations increase in the inland areas as the wind decreases.

Average annual rainfall varies from 200 to 340mm and precipitation usually occur in the months of January, February and March. Very heavy falls can occur occassionally which cause widespread flooding in local area and may make roads impassable. Tropical cyclones are common in the Pilbara between November and April. They usually follow a southwesterly course parallel to the coast, then cross the coast and move inland. The heavy rain brought in by the cyclones and the accompanying storm

surge can cause extensive inundation of the lower lying Pilbara terrain, making movement of both track and wheeled vehicles impossible.

Kimberley

The Kimberley receives a much higher annual rainfall than the neighbouring Pilbara. The annual average varies between 350mm in the south to over 1400mm near the north. The most prevalent factor contributing to the higher rainfall in this region is the tropical low pressure system. Cold winds from central Asia blow over the South China Sea and through the Timor Sea; carrying moisture into the Kimberley. This results in heavy rainfall which usually occurs from late November to early March. From March to November, the anticyclones that travel across the arid interior in an easterly direction will give rise to the 'dry' season in the region.

The Kimberley is also subject to high temperatures with November as the hottest month. The maximum temperature fluctuates between 42 to 45°C and drops an average of 10°C at night. In July, temperature becomes cooler and averages 18 to 23°C. The area is generally frost free. During September to October, the temperature rises rapidly and, together with an increase in relative humidity, produces an uncomfortable outdoor environment.

The Kimberley is also under the influence of tropical cyclones between late November to early April. Rainfall is generally light if the cyclone runs parallel to the coast. Once it crosses the coast, however, rainfall is usually heavy particularly in those areas along the cyclone track. Flooding of the lower ground is also very common; resulting in limited access to flooded areas.

Arnhem Land

The Arnhem land is also under the influence of monsoonal climate with two distinct seasons. These are the hot, wet season from November to March and the hot, dry season from May to September. The climate becomes drier inland and the temperature also fluctuates more. Similar to the Kimberley, there is a very uncomfortable hot and humid period prior to the start of the wet season. Occasionally there may be thunderstorms relieving the oppressive heat. The hottest month of the year is November with average maximum temperature of 33°C. In June and July, the daily maximum is a mild 19°C and rarely falls below 16°C. Relative humidity is high and reaches 70 to 80% for most of the wet season.

The wet season commences when the low pressure systems of Northern Australia join with the intertropical convergence zone. This allows the inflow of warm, moist maritime air from the north-west into the region. Periods of one to several days of monsoon weather, typified by cloudy conditions and heavy rainfall interspersed by sunny, hot and humid days are very common. The dry season is predominated by

south-easterly trade wind with cloudless skies and lower humidity. The annual rainfall ranges from 400mm in the inland to over 1200mm towards the coastal regions. Arnhem Land is visited by two to three cyclones per year. They usually originate in the Indian Ocean and Timor sea, crossing the coastline and bring in heavy rains and destructive wind. Flooding over a large part of the region is very common and extreme low pressure cyclonic depressions can affect the weather for up to several weeks. When this happens, off-road vehicular movement is impossible and foot patrols are severely restricted by inundation. Radiocommunication can also be greatly disturbed by these low pressure systems.

Cape York Peninsula

Similar to most other regions in the North, Cape York Peninsula has a typical summer wet and winter dry climate. The summer wet season caused by monsoon conditions, is short and occurs from early December to late February. The dry winter extends from March to November but may shift from year to year. Temperatures average 22 to 34°C in summer and 18 to 32°C in winter. Relative humidity is high and may reach 70% and above in the hotter months. In winter, it drops slightly to 60%. Rainfall in Cape York Peninsular is mainly attributable to monsoonal winds and tropical cyclones. The north-westerly flow of monsoon brings in moisture over the region. Along the coastal districts of northeast Cape York, annual rainfall of 1500mm or more is very common. This rapidly decreases towards the more inland areas.

Tropical cyclones in this region are often destructive. Wind speed of up to 200km/h had been recorded. These cyclones occur between December and April and usually bring in intense rainfall. As the road infrastructure in this part of Northern Australia is relative primitive, most of Cape York Peninsula will become inaccessible to vehicles particularly after heavy falls. The river system in the area, however, is extensive. Access to remote areas by waterways may be possible.

The Great Dividing Range and South-East Queensland

The weather of east-central and south-east Queensland is strongly influenced by a quasi-monsoon climate. The region is dominated by trade winds from inland in summer and south-easterly winds in winter. Temperatures in the coastal region are buffered by the sea breeze and are milder. They ranges from 18 to 32°C in summer and 14 to 22°C in winter. Rainfall in this part of Australia is relatively high and is evenly distributed. Annual averages consistently break the 1200mm mark. Summer rains come mostly from the east bringing moist air streams from the tail end of anticyclonic systems of the Pacific. The surface pressure trough between two anticyclones often continues to expand upward and forms a large low pressure system. This brings torrential rains and may cause disastrous flooding to low areas. Towards southwest of the Great Dividing Range the climate becomes drier and hotter.

Road systems in the coastal plain are well built and maintained. The drainage is adequate and access to this region by road is good. Inland, the rugged terrain restricts road access during wet season. Air operations are also restricted as the thick forests of the Great Dividing Range make landing difficult.

6. Environmental Stressors

The most significant environmental stressors that may have an impact on the physiology and performance of military staff deployed to the north are the heat and high humidity. The influence of and the ability of the body to adjust physiologically to these stressors will depend on a number of factors. These may include the duration and level of physical activity, the efficiency of the cardiovascular system, the physical barrier (type of clothing) to heat dissipation, the availability of fluid to cover loss by sweating and the ambient environment. Collectively they will determine heat exchange between the body and its environs.

The ambient environment refers to the immediate surroundings of the thermally stressed human body. The higher the ambient temperature and relative humidity, the more difficulty the body will have to get rid of excess body heat. The amount of metabolic heat produced is governed by the level of physical exertion. The more efficient the cardiovascular system, the better the ability the circulation to bring the heat to the surface of the body for transfer to the outside. It is therefore important to put on clothing that least obstructed heat transfer. When the ambient temperature is higher than the body temperature, heat can only be lost by evaporative cooling. Fluid replenishment to cover loss by sweating is critical under this circumstance to avoid heat stress.

Other important environmental factors that may affect military activity in Northern Australia are the strong winds and dust storms. These can be generated either naturally or by vehicles and aircraft. Dust and sand that enter the eyes can cause great irritation and injury to soft tissues. They can also abrase wounds, produce skin rashes and cause cracked lips which discourage eating. Strong and dry wind can damage the mucous membrane lining the nostrils and throat, thus giving rise to nose and buccal bleeds. All these may produce a deterioration in morale and physical performance.

The sky in the north is usually clear and this results in an increase of direct sun exposure. As soldiers may receive more UV irradiation than normal, the risk of contracting more serious skin disease may increase. Sun glare may hurt the eyes and affect a soldier's ability to track enemy movement. Painful sun burn may also be a problem for pilots flying long hours.

Whilst conducting military operation, it is not unusual for soldiers to come across poisonous flora and fauna and infectious micro-organisms. The chance of contracting a disease is particularly high in areas where sanitation is poor and personal hygiene is

neglected. If there is an out-break of contagious disease, the results are usually serious and can be fatal. These effects are ameliorated by proper hygiene education provided to all troops to increase their awareness of these health issues. Adequate planning and preparation will protect soldiers from unnecessary risk which can degrade their effectiveness and disrupt operations.

7. Physiological Performance

Previous experience has suggested that the most debilitating factors in the north in outdoor activities are the intensive heat and high humidity. In normal circumstances, the body will respond by initiating the thermoregulatory processes to protect from overheating (16). Heat production in the body can be linked to basal metabolic activities and muscular movements. Heat can also be gained from external environment via solar radiation, from contact with hot objects and from air layers hotter than the body. To maintain a constant body temperature, the heat gain is compensated from loss by physical mechanisms such as conduction, convection, radiation and evaporative cooling. If heat production outstrips heat loss, the core temperature will rise. The increase in deep body temperature, within limits, does not necessarily reflect a failure of heat dissipation. A modest rise actually indicates that adaptive processes are functioning. These changes will maintain an optimal thermal environment for physiological functions. In extreme case, human body can tolerate up to 5°C above the normal body temperature for a short period of time (17). When core temperature is sustained at 40°C or above, however, the chance of heat stroke and other related injuries to occur will be very high (18,19). Medical attention must be given to the victim urgently, otherwise the outcome may be fatal.

In tropical conditions, the basal metabolic rate may be 5 to 20% higher than the rate at cooler climates. In addition, there can be an increase of up to 5% in oxygen consumption (17). Thus, even when same work is performed, subjects working in hotter environments will have a bigger basal thermal stress. When performing sustained physical exercise, metabolic rate for an individual may reach 20 to 25 times the basal metabolic rate. This would theoretically raise the core temperature by 1°C every 5 minutes (17). Consequently, the circulating blood is warmer when perfusing the anterior hypothalamus which subsequently activates the thermal receptor cells. These cells then relay the message to other thermal regulatory centers of the hypothalamus to initiate co-ordinated responses for heat dissipation.

For a thermally stressed individual, the heart rate and stroke volume will increase initially in response to a rise in core temperature; thus increasing the total cardiac output. Thereafter, the heart rate starts to fall but stroke volume is roughly maintained (20). To maximize heat dissipation capacity, 15 to 20% of the plasma flow will by-pass the non-critical heat dissipating tissues or organs such as kidney and liver so that heat energy can be readily transferred to the external environment (21). There are also hormonal changes to facilitate the heat dissipating process. The pituitary gland in the

brain will increase the release of anti-diuretic hormone(ADH) for fluid conservation (22), while the adrenal cortex will release aldosterone to retain sodium (23). Together with a reduction of plasma volume due to sweating, blood pressure is maintained at a high level to ensure consistent supply of blood to the periphery.

In conditions when external temperature is higher than the core temperature, body heat can be lost only by evaporative cooling. The importance of maintaining fluid intake to replace loss cannot be overemphasised. Most individuals can lose 1 to 1.5 litres per hour when working modestly in the heat (24) but daily turnover can be as high as 15 litres in desert environment (25). The body heat is taken away by evaporating a hypotonic fluid secreted by the sweat gland. For each litre of water vaporized, 580 kcal of heat energy is extracted from the body (17). Sustained loss of water by intense sweating can lead to fatigue of sweat gland; resulting in diminishing heat dissipating capacity. Under the same working conditions and environment, a subject with weight loss of 5% because of dehydration will register a much higher core temperature than the one fully hydrated (26). The thermoregulatory capacity of a dehydrated subject is greatly compromised. Furthermore, the physical performance and physiological conditions of an individual will rapidly deteriorate if fluid loss by sweating is not replenished. On top of a rapid rise of core temperature, a 4 to 5% weight loss as a result of dehydration will cause a significant reduction in plasma and stroke volume, a higher heart rate and a gentle decline in circulatory and thermoregulatory efficiency. There could be a 50% reduction in endurance and a drop of more than 20% of maximum oxygen consumption (27, 28). Effective thermoregulation is dependent on adequate hydration for anyone engaging in strenuous exercise in the heat.

The ability to withstand the deleterious effects of heat can be enhanced by a combination of physical training and acclimatization. Maintaining a high level of physical fitness through regular exercise reduces the time taken to achieve acclimatization to heat. Training develops a more responsive heat regulatory mechanism by improving the cardiovascular efficiency, reducing fat content and increasing aerobic capacity. Thus the body can then be cooled more economically. Physical training is usually carried out in conjunction with programmed exposure to higher temperature. The physiological adaptive measures for heat are collectively termed as heat acclimatization. The changes induced by heat acclimatization are basically similar to those due to physical training. During heat acclimatization, there is a gradual increase in cutaneous blood flow and cardiac output (29). The threshold for sweating is lowered and sweat is more evenly distributed over the surface of the skin. Reabsorption of salt from sweat is also increased (30). These responses will bring about increased circulation to the periphery, higher cutaneous blood flow, earlier onset of sweating to maximize evaporative cooling and preservation of electrolytes in the extracellular fluid. As a result, a fully acclimatized and physically fit person can maintain the same body temperature despite the higher workload required. This is based on the conditions that the subject is fully hydrated and there is no impediment to evaporative cooling.

8. Recommendations for Future Research

The high heat and humidity in the north are the most stressful environmental factors. They can impair the health and performance of soldiers and therefore, can potentially cripple military missions. Other environmental conditions such as the rugged terrain, dust storms, solar radiation, tropical cyclones, flooding and bush fires add to the difficulty in maintaining ADF's operational efficiency. Without adequate support and preparation, the occurrence of significant heat casualties would be very high. The strategy to minimize this risk to soldiers will rely on the correct applications of risk management techniques and preventive medical principles.

There are overseas defence institutes actively engaging in thermal and exercise physiological research. For example, the US Army Research Institute of Environmental (USARIEM) and the Defence and Civil Institue of Environmental Medicine (DCIEM) of Canada are two leading research institutes that focus on the development of technology that enhances survival, protection and physical performance of military personnel in adverse environments. Through membership of the Technical Cooperation Program (TTCP), Australia recieves invaluable information and technologies from its allies which benefit the ADF to improve its operational efficiency in the north. Yet the unique Australian environments make it imperative for the scientific arm of the Defence Department to establish research capabilities to meet the special challenges of military operation in Northern Australia. The Defence Science and Technology Organization (DSTO) has built up a limited capacity to investigate human performance under different military scenarios in tropical conditions. It is important for DSTO to maintain a moderate expansion in this area to provide adequate support to the ADF. Collaboration with local and international agencies should be actively promoted to alleviate the pressure to compete for the scarce resources DSTO is allocated.

To enhance the physiological capability and flexibility of our Defence forces operating in the north, research must be orientated towards the development of technology that can increase the survivability and sustainability of troops exposed to these environmental stressors. Based on these requirements and the experience and information collected from the visits to military units in the north, research in the following areas is recommended.

- Baseline studies on heat stress and related problems for deployment to the north. Special emphasis will be placed on those situations in which ADF personnels are required to work in extremely stressful environments such as air operations, mounted and dismounted surveillance.
- Develop and assess the effectiveness of a heat stress monitoring/warning device for field use.
- Evaluate computer models for the prediction of body temperature and heat stress problems under various military scenarios.

- Develop and evaluate the suitability of new clothing fabrics as military uniform for wearing in hot environment. This may include integrating protective and personal equipment within the new uniform.
- Develop and explore technologies to reduce physiological strain as a result of heat stress eg. IPECS and cooling vest.
- Investigate the dynamics of fluid conservation, electrolyte balance and their impacts on evaporative cooling mechanism.
- Develop and evaluate suitable eye protection against dust and foreign particles.
- Develop strategy and procedures for screening new recruits for deployment to the north.
- Exploit the possibility of using ergogenic aids for performance enhancement.
- Introduce and integrate physiological strains as a component of operational analysis.
- Investigate the effects of heredity, morphological and developmental factors (eg. age, gender, body build) on the relationship between physical training, heat acclimatization and exercise-heat tolerance.

This list of research recommendations is by no means exhaustive. If they, however, are agreed and thoroughly investigated, useful answers will be available to ADF to address its concerns on heat stress and related problems for deployments and operations in Northern Australia. Priority should be given to those areas which affect operational effectiveness. These include the development of heat stress monitoring and warning device, the exploration and applications of active personal cooling technologies, acclimatization protocol study and evaluation of severity of heat stress problems. The recommendation excludes cognitive investigation as it is outside the scope of this study. Nevertheless, it is an important area and should be addressed separately.

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19. ABSTRACT

Deployment of military staff to the north exposes them to the debilitating effects of high heat and humidity. This paper summarises the findings of a series of visit to several military establishments in northern Australia and a training battalion in NSW. Areas of research priority were identified and recommendations were given to address ADF's requirements in human physiological performance and survavibility in adverse environments.

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